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MISSISSIPPI RIVER COMMISSION

VACUUM TANK TESTS OF MODEL TAINTER VALVE FOR McNARY DAM

TECHNICAL MEMORANDUM NO. 2-282

WATERWAYS EXPERIMENT STATION

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PREFACE

The investigation described in this report was authorized by the District Engineer, Portland District, CE, in a letter dated 15 January 1948 to the Waterways Experiment Station, subject: "Vacuum Tank Tests of Model Tainter Valve." The tests were conducted by the Hydraulics Division of the Waterways Experiment Station during the period March-June 1948. Engineers actively connected with the study were Messrs. E.P. Fortson, Jr., F.R. Brown, T.E. Murphy, and John W. Bolin.

CONTENTS

VACUUM TANK TESTS OF MODEL TAINTER VALVE

FOR McNARY DAM

Introduction

1. McNary Dam, one unit in the comprehensive development of the Columbia and Snake Rivers in Oregon, consists of a gate-controlled spillway of twenty-two 50-ft bays, a powerhouse for fourteen 95,400-hp turbine generator units, a single-lift navigation lock 86 by 675 ft with approach guide walls, facilities for migrating fish, and two earth-fill abutments. Total length of the project is approximately 7,300 ft; average head is 85 ft.

2. It is proposed to use a tainter valve to control flow through the lock culvert at McNary Dam. Model tests of the culvert and valve were conducted under atmospheric conditions at the Bonneville Hydraulic Laboratory, CE, Bonneville, Oregon. These tests revealed negative pressures dangerously near the cavitation range in the culvert immediately downstream from the tainter valve. Since the Waterways Experiment Station had available a vacuum tank, the District Engineer, Portland District, requested that tests be conducted therein to determine whether cavitation actually would occur below the valve. This report presents the results of those tests.

3. The lock culvert at the valve section is 11 ft wide by 12 ft high. The valve is placed so that the well is on the high head side to prevent air from being drawn down the well and causing turbulence in the lock chamber.

4. A 1:20-scale model, reproducing 70 ft of culvert upstream from the valve, the valve, and 65 ft of culvert downstream from the valve, was used for the study.

5. Since it was possible to install only a short section of the culvert in the vacuum tank, it was necessary to establish hydraulic conditions at the valve section from data obtained on the general lock model tested at the Bonneville Hydraulic Laboratory. Table 1 presents discharge values and pressures at three rings of piezometers for the heads at which the valve was tested. Locations of the rings of piezometers are shown on plate 1. Since pressures at the two piezometer rings downstream from the valve (rings B and C) fluctuated considerably, hydraulic conditions at the valve were established by setting the valve opening and corresponding discharge and then adjusting the tailwater at the lower end of the model section until the proper grade line was obtained at piezometer ring A.

Tests and Results

6. Initial tests consisted of pressure measurements made under atmospheric conditions. Pressures were measured with the culvert invert at elevation 228* and with the culvert lowered by 5-ft stages to elevation 208. This was the maximum lowering of the culvert considered practical. Pressures measured are recorded in tables 2-6, while locations of piezometers are shown on plate 1. Minimum pressures were observed on the roof of the culvert immediately below the valve with the valve open 7 ft. With the culvert invert at elevation 228 the minimum pressure

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* All elevations are in feet above mean sea level.

amounted to -18.8 ft of water. As the culvert was lowered pressures were increased by approximately the amount of the lowering. With the culvert at elevation 208 no negative pressures were observed.

7. In order to evaluate cavitation data, a parameter K was established at piezometer ring A based on pressure and velocity data recorded on the over-all model investigated at the Bonneville Hydraulic Laboratory and on assumed prototype temperatures and barometric pressure. This parameter was expressed in the form $K = \frac{h_o - h_v}{\frac{V_o^2}{2g}}$ wherein h_o was the absolute pressure at piezometer ring A, h_v was the vapor pressure of the water in the prototype (assumed to be 60 F), V_o was the average velocity at piezometer ring A, and g was the acceleration due to gravity. The value of h_o was obtained by adding the piezometric pressure measured in the over-all model to the assumed prototype atmospheric pressure (33.9 ft of water). For critical valve openings, this parameter was plotted against the elevation of the culvert invert (plate 2). Computations are shown in tables 7, 9, and 11. Since model and prototype are geometrically similar cavitation will occur in the prototype at the same value of K at which it occurred in the model. Cavitation data were obtained in the model by establishing the proper hydraulic conditions and then lowering the pressure in the system until cavitation flashes were observed at any place in the test section. From data taken on the model at the point of incipient cavitation the value of K at piezometer ring A was computed. This value of K has been designated the cavitation index, K_i, or the value at which cavitation flashes began to appear in the test section.

(Roof of culvert should probably be used since lowest pressure is on roof) ✓

8. Since minimum pressures were measured with the valve open 7 ft, initial cavitation tests were made at this opening. Data on the cavitation parameter for a valve opening of 7 ft, computed as explained above, are contained in table 7 and a plot of the cavitation parameter against culvert invert elevation is presented on plate 2. Based on observations at reduced pressures and hydraulic conditions simulating those that would obtain with the culvert invert at various elevations from 228 to 208, an average value of K_i of 8.51 was obtained (table 8). This value corresponded to the value of the cavitation parameter that would obtain in the prototype culvert with the invert at elevation 177.2 (plate 2). Thus it would be necessary to lower the culvert invert to below elevation 177.2 to eliminate cavitation completely when the valve is open 7 ft. Photographs 1-5 show cavitation below the valve for cavitation parameters representing prototype conditions with the culvert invert at elevations 228, 223, 218, 213, and 208. For all cases the cavitation pockets formed at the lip of the valve, moved downstream and collapsed a considerable distance from the valve.

9. In like manner it was determined that to eliminate cavitation when the valve is open 6 ft and 8 ft it would be necessary to lower the culvert invert to elevations 189.8 and 196.4, respectively. See tables 9-12 and plate 2.

10. In order to obtain an indication of the pressure fluctuations in the culvert, three electric pressure cells were installed downstream from the valve at locations shown on plate 1. Tests were made with these cells solely to determine pressure fluctuations due to turbulence. Because of their size, the cells were unsuitable for measuring local

pressures at the collapse of cavitation pockets. The data obtained should be considered as an indication only, since it was impossible to determine the point at which maximum pressure fluctuation occurred.

11. Details of the pressure cell may be seen on plate 1, while photograph 6 shows a completely assembled cell. The measuring face of a cell of the type used consists of a thin diaphragm with an effective area of 2.41 sq in. Two electrical resistance strain gages of the SR-4 type are bonded to the inner face of the diaphragm to form one-half of an electrical bridge circuit. These gages are positioned in such a manner that one gage is under maximum compressive strain at the same time the second gage is under maximum tensile strain; such an arrangement gives maximum output for a given pressure change. As pressure is applied to the face of the cell, the diaphragm undergoes strain which causes the resistance grid in the electrical strain gage to change in resistance. The resistance change causes a change in the current flow in the bridge circuit. As this change of current flow is necessarily small, amplifiers are required to magnify the change so that it can be recorded by an oscillograph.

12. The cells were calibrated in a pressure tank to determine their resistance change for a range of pressures from -34 to +34 ft of water. Instantaneous pressures were measured with prototype cavitation conditions reproduced; no readings were taken with the model under atmospheric pressure. Listed in table 13 are maximum and minimum pressures measured with tank conditions simulating the prototype conditions with the culvert invert at elevations 228, 223, 218, 213, and 208. Typical oscillograph records are illustrated on plates 3 and 4.

Conclusions

13. The model tests proved that cavitation will occur in the prototype unless the invert of the culvert at the valve section is lowered to about elevation 177, or some other means is adopted to reduce the severity of cavitation conditions. However, the extent of the damage that will be caused by the cavitation is difficult to predict. No doubt there will be some pitting of the culvert walls even though the majority of the cavitation pockets appeared to collapse in the stream of flow away from the roof or walls of the culvert.

14. In general it is desirable to design a structure so as to insure against the existence of any cavitation. For the case at hand it may be more economical to allow some cavitation and provide for periodic replacement of the culvert lining immediately below the valve. If this is done, consideration should be given to lining the culvert with a material that is highly resistant to damage by cavitation.

15. If the design of the prototype valve section is not revised to eliminate all cavitation, it is recommended that frequent inspections of the prototype be made. Since it is difficult to predict the actual damage that will be caused by cavitation, inspections will be necessary to guard against a major failure.

Table 1

PRESSURES OBTAINED UNDER ATMOSPHERIC CONDITIONS ON GENERAL LOCK MODEL

Tainter Valve Opening (ft)	Discharge (cfs)	Elevation of pressure grade line above bottom of culvert		
		Ring A Piez. Nos. 28, 29	Ring B Piez. Nos. 30, 31, 32, 33	Ring C Piez. Nos. 34, 35, 36, 37
4.0	2,470	105.6	-2.4	2.7
5.0	3,200	101.8	-4.5	1.8
6.0	3,970	96.2	-4.6	3.3
7.0	4,780	89.2	1.4	11.2
8.0	5,440	81.6	14.6	24.0
9.0	6,120	73.4	29.5	35.9

Stable

+4-5 ft fluctuations

Table 2

PRESSURE DATA
Culvert Invert Elev 228 msl

Piezometer No.	Valve Opening 4 ft	5 ft	6 ft	7 ft	8 ft	9 ft
Ring A	105.6	101.8	96.2	89.2	81.6	73.4
Ring B	1.8	0.0	2.0	4.8	18.8	36.8
Ring C	4.6	4.4	9.0	15.2	28.8	43.4
4	-7.2	-9.2	-2.0	-9.4	4.2	12.8
5	-12.6	-17.2	-17.6	-18.8	-10.2	-2.0
6	6.4	10.8	16.6	20.4	27.8	33.6
7	---	----	----	----	----	----
8	-11.2	----	----	----	----	----
9	-7.6	-11.0	-13.4	-15.0	-8.4	----
10	-4.8	-8.0	-10.2	-10.4	-4.0	4.2
11	-2.6	-6.2	-9.4	-10.6	-3.4	3.8
23	-13.2	-16.0	-15.8	-16.6	-7.6	6.4
24	-10.8	-12.6	-10.4	-5.4	9.4	27.0
25	2.8	0.6	4.2	8.2	22.0	38.0
26	-10.4	-16.0	-16.8	-17.2	-9.4	0.0
27	-9.6	-16.0	-16.8	-17.2	-10.2	-1.6

Table 3

PRESSURE DATA
Culvert Invert Elev 223 msl

Piezometer No.	Valve Opening 4 ft	5 ft	6 ft	7 ft	8 ft	9 ft
Ring A	110.6	106.8	101.2	94.2	86.6	78.4
Ring B	6.4	4.6	7.4	10.8	23.8	40.8
Ring C	10.4	9.8	15.8	20.6	34.8	48.0
4	-1.8	-4.4	-3.4	-1.2	9.0	18.4
5	-7.6	-11.6	-12.0	-13.2	-5.4	2.6
6	12.4	15.8	22.8	24.8	33.0	37.8
7	----	----	----	----	----	----
8	-6.4	----	----	----	----	----
9	-3.0	-7.0	-7.2	-9.8	-2.8	----
10	-0.2	-4.0	-5.8	-5.4	1.2	9.0
11	1.0	-3.0	-3.4	-5.0	2.0	9.2
23	-7.6	-11.4	-10.6	-11.2	-2.0	11.2
24	-5.4	-8.4	-4.0	-0.6	14.4	32.4
25	8.0	6.8	11.0	14.4	27.4	42.4
26	-7.2	-11.2	-9.4	-11.2	-3.6	4.8
27	-7.6	-10.6	-9.4	-12.6	-5.6	3.0

Notes: Pressures are recorded in prototype feet of water.
Pressures at rings A, B and C are referred to floor of culvert.
All other pressures referred to piezometer location.

Table 4

PRESSURE DATA
Culvert Invert Elev 218 msl

Piezometer No.	Valve Opening					
	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft
Ring A	115.6	111.8	106.2	99.2	91.6	83.4
Ring B	14.4	8.4	12.2	14.2	29.2	45.8
Ring C	16.4	13.0	19.2	24.0	40.0	53.0
4	4.8	-1.6	2.4	2.4	14.2	23.4
5	-2.4	-7.0	-7.2	-8.4	0.2	8.0
6	18.8	18.8	26.4	29.6	36.8	43.8
7	----	----	----	----	----	----
8	-1.2	----	----	----	----	----
9	2.8	-4.2	-3.2	-5.4	2.6	----
10	5.6	-0.8	0.2	-1.0	7.0	14.0
11	7.4	-1.0	0.6	-1.4	6.6	14.0
23	-2.0	-8.4	-6.4	-7.0	2.4	17.0
24	0.0	-5.6	0.2	3.0	20.6	36.2
25	13.8	10.2	14.8	19.0	32.8	47.4
26	-3.6	-8.0	-6.8	-7.4	1.2	9.6
27	-2.6	-8.0	-8.2	-8.2	0.2	8.2

Table 5

PRESSURE DATA
Culvert Invert Elev 213 msl

Piezometer No.	Valve Opening					
	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft
Ring A	120.6	116.8	111.2	104.2	96.6	88.4
Ring B	17.8	14.0	16.0	18.8	33.4	51.2
Ring C	20.8	19.2	24.0	29.2	44.2	58.4
4	9.2	5.0	6.0	7.4	18.6	28.6
5	2.6	-2.0	-2.0	-4.0	4.2	12.8
6	22.4	25.0	30.8	34.0	41.8	48.0
7	----	----	----	----	----	----
8	3.2	----	----	----	----	----
9	6.8	2.2	1.0	-1.0	6.4	----
10	9.6	5.4	4.2	3.0	11.2	18.8
11	11.2	5.8	4.8	3.2	11.2	19.2
23	2.2	-1.6	-1.4	-3.4	7.0	21.2
24	4.8	3.2	5.0	7.2	24.0	42.6
25	17.8	16.8	19.2	23.0	37.6	52.8
26	-0.8	0.6	-1.6	-2.2	5.6	15.0
27	-0.8	0.6	-3.4	-3.2	4.4	13.0

Notes: Pressures are recorded in prototype feet of water.
Pressures at rings A, B and C are referred to floor of culvert.
All other pressures referred to piezometer location.

Table 6

PRESSURE DATA
Culvert Invert Elev 208 msl

Piezometer No.	Valve Opening 4 ft	5 ft	6 ft	7 ft	8 ft	9 ft
Ring A	125.6	121.8	116.2	109.2	101.6	93.4
Ring B	24.0	19.0	22.4	25.2	41.4	56.0
Ring C	26.2	25.0	29.6	34.4	51.0	62.8
4	14.8	11.2	12.2	13.6	24.8	33.2
5	9.2	4.0	3.4	2.2	10.6	18.4
6	28.6	30.6	36.0	40.6	49.0	54.0
7	----	----	----	----	----	----
8	9.6	----	----	----	----	----
9	13.2	8.0	7.0	5.6	12.6	----
10	16.0	11.0	10.2	9.6	17.4	24.8
11	16.6	11.8	10.0	10.0	17.2	24.6
23	8.2	3.8	3.8	3.8	12.6	27.2
24	10.8	8.8	11.0	15.0	30.2	47.6
25	23.6	21.6	25.2	29.6	43.0	58.0
26	6.0	4.6	3.2	3.2	12.0	20.4
27	3.4	4.2	0.2	2.6	10.8	18.8

Notes: Pressures are recorded in prototype feet of water.
Pressures at rings A, B and C are referred to floor of culvert.
All other pressures referred to piezometer location.

Table 7

CAVITATION PARAMETER AT PIEZOMETER RING A

VALVE OPEN 7 FT

DISCHARGE 4780 CFS

Elev of Culvert Invert	Hydraulic Pressure (From Tables 2-6) Ft of Water	Atmospheric Pressure (Assumed) Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature (Assumed) Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K Cavitation Parameter $\frac{h_o - h_v}{V_o^2/2g}$
228	89.2	33.9	123.1	60	0.59	36.2	20.3	6.04
223	94.2	33.9	128.1	60	0.59	36.2	20.3	6.28
218	99.2	33.9	133.1	60	0.59	36.2	20.3	6.53
213	104.2	33.9	138.1	60	0.59	36.2	20.3	6.77
208	109.2	33.9	143.1	60	0.59	36.2	20.3	7.02

Table 8

CAVITATION INDEX AT PIEZOMETER RING A

VALVE OPEN 7 FT (PROTOTYPE)

DISCHARGE 4780 CFS (PROTOTYPE)

8.0 based on roof pressure

Based on Piez Ring C and roof

Elev of Culvert Invert (Prototype)	Hydraulic Pressure (From Tables 2-6) Ft of Water	Tank Pressure for Incipient Cavitation Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature for Incipient Cavitation Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K_i Cavitation Index $\frac{h_o - h_v}{V_o^2/2g}$
228	4.46	4.94	9.40	63.5	0.67	8.09	1.02	8.60
Piez Ring C (avg)	.16		5.10		5.10 .43			4.35
223	4.71	4.65	9.36	68.0	0.78	8.09	1.02	8.45
218	4.96	4.51	9.47	66.5	0.74	8.09	1.02	8.60
213	5.21	4.40	9.61	69.0	0.81	8.09	1.02	8.66
208	5.46	3.83	9.29	72.0	0.90	8.09	1.02	8.26
								Av K_i = 8.51

NOTES: K_i is the value of the cavitation parameter at piezometer ring A at which cavitation was incipient immediately downstream from the valve.

All quantities are model equivalents unless otherwise noted.

Ring C pressures fluctuate rather badly so arbitrary Ring A selection appeared better.

Pressure reduction from Ring A in terms of the velocity head in full-flowing culvert.

Table 9

CAVITATION PARAMETER AT PIEZOMETER RING A

VALVE OPEN 6 FT

DISCHARGE 3970 CFS

Elev of Culvert Invert	Hydraulic Pressure (From Tables 2-6) Ft of Water	Atmospheric Pressure (Assumed) Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature (Assumed) Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K Cavitation Parameter $\frac{h_o - h_v}{V_o^2/2g}$
228	96.2	33.9	130.1	60	0.59	30.1	14.1	9.20
223	101.2	33.9	135.1	60	0.59	30.1	14.1	9.55
218	106.2	33.9	140.1	60	0.59	30.1	14.1	9.90
213	111.2	33.9	145.1	60	0.59	30.1	14.1	10.25
208	116.2	33.9	150.1	60	0.59	30.1	14.1	10.60

Table 10

CAVITATION INDEX AT PIEZOMETER RING A

VALVE OPEN 6 FT (PROTOTYPE)

DISCHARGE 3970 CFS (PROTOTYPE)

Elev of Culvert Invert (Prototype)	Hydraulic Pressure (From Tables 2-6) Ft of Water	Tank Pressure for Incipient Cavitation Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature for Incipient Cavitation Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K_i Cavitation Index $\frac{h_o - h_v}{V_o^2/2g}$
228	4.81	4.31	9.12	70.0	0.84	6.72	0.70	11.82
223	5.06	4.03	9.09	77.0	1.06	6.72	0.70	11.46
218	5.31	4.26	9.57	79.0	1.13	6.72	0.70	12.04
213	5.56	4.15	9.71	81.0	1.21	6.72	0.70	12.12
208	5.81	4.02	9.83	80.0	1.17	6.72	0.70	12.36
								Av K_i = 11.96

NOTES: K_i is the value of the cavitation parameter at piezometer ring A at which cavitation was incipient immediately downstream from the valve.

All quantities are model equivalents unless otherwise noted.

Table 11

CAVITATION PARAMETER AT PIEZOMETER RING A

VALVE OPEN 8 FT

DISCHARGE 5440 CFS

Elev of Culvert Invert	Hydraulic Pressure (From Tables 2-6) Ft of Water	Atmospheric Pressure (Assumed) Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature (Assumed) Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K Cavitation Parameter $\frac{h_o - h_v}{V_o^2/2g}$
228	81.6	33.9	115.5	60	0.59	41.2	26.4	4.35
223	86.6	33.9	120.5	60	0.59	41.2	26.4	4.54
218	91.6	33.9	125.5	60	0.59	41.2	26.4	4.73
213	96.6	33.9	130.5	60	0.59	41.2	26.4	4.92
208	101.6	33.9	135.5	60	0.59	41.2	26.4	5.11

Table 12

CAVITATION INDEX AT PIEZOMETER RING A

VALVE OPEN 8 FT (PROTOTYPE)

DISCHARGE 5440 CFS (PROTOTYPE)

Elev of Culvert Invert (Prototype)	Hydraulic Pressure (From Tables 2-6) Ft of Water	Tank Pressure for Incipient Cavitation Ft of Water	h_o Absolute Pressure Ft of Water	Water Temperature for Incipient Cavitation Degrees F	h_v Vapor Pressure of Water Ft of Water	V_o Velocity Ft/Sec	Velocity Head $\frac{V_o^2}{2g}$	K_i Cavitation Index $\frac{h_o - h_v}{V_o^2/2g}$
228	4.08	3.94	8.02	69.0	0.81	9.2	1.32	5.47
223	4.33	3.83	8.16	68.5	0.80	9.2	1.32	5.58
218	4.58	3.54	8.12	70.0	0.84	9.2	1.32	5.51
213	4.83	3.43	8.26	71.0	0.87	9.2	1.32	5.59
208	5.08	3.26	8.34	72.0	0.90	9.2	1.32	5.63
								Av K_i = 5.56

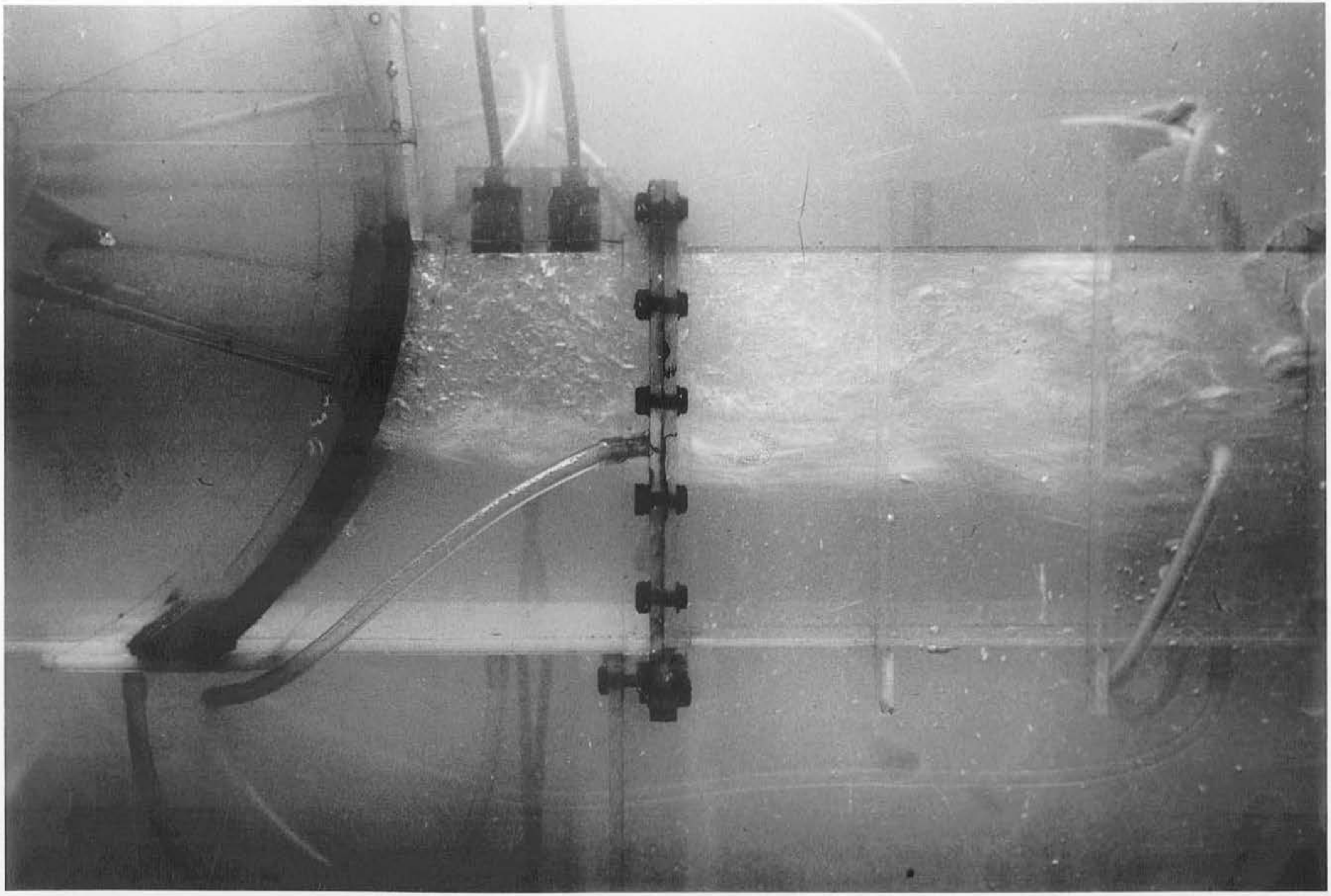
NOTES: K_i is the value of the cavitation parameter at piezometer ring A at which cavitation was incipient immediately downstream from the valve.

All quantities are model equivalents unless otherwise noted.

Table 13

INSTANTANEOUS PRESSURES
VALVE OPEN 7.0 FT
DISCHARGE 4780 CFS

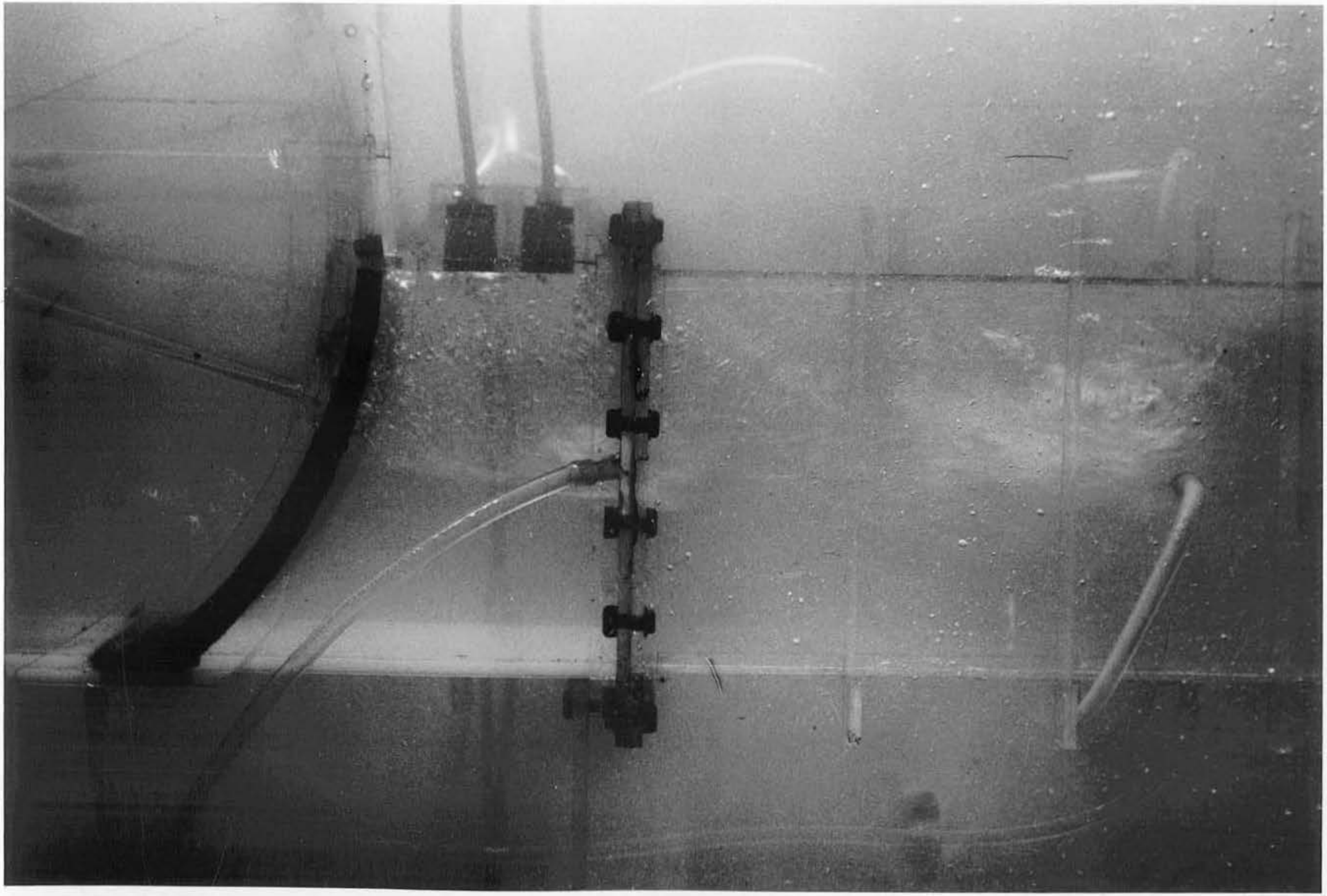
Culvert invert elev	Cavitation parameter at piezometer ring A	Cell number	Maximum pressure (ft of water)	Minimum pressure (ft of water)
228 msl	6.04	1	-8.6	-26.4
		2	1.8	-16.5
		3	16.6	-24.6
223 msl	6.28	1	-1.4	-23.0
		2	9.8	-12.0
		3	22.0	-24.8
218 msl	6.53	1	1.0	-19.0
		2	11.6	-14.0
		3	19.6	-19.4
213 msl	6.77	1	8.8	-8.8
		2	13.2	-9.4
		3	36.2	-21.2
208 msl	7.02	1	13.0	-6.0
		2	21.2	-2.8
		3	37.4	-13.2



Culvert invert elev 228, tainter valve open 7 ft, discharge 4,780 cfs
Cavitation parameter at piezometer ring A = 6.04

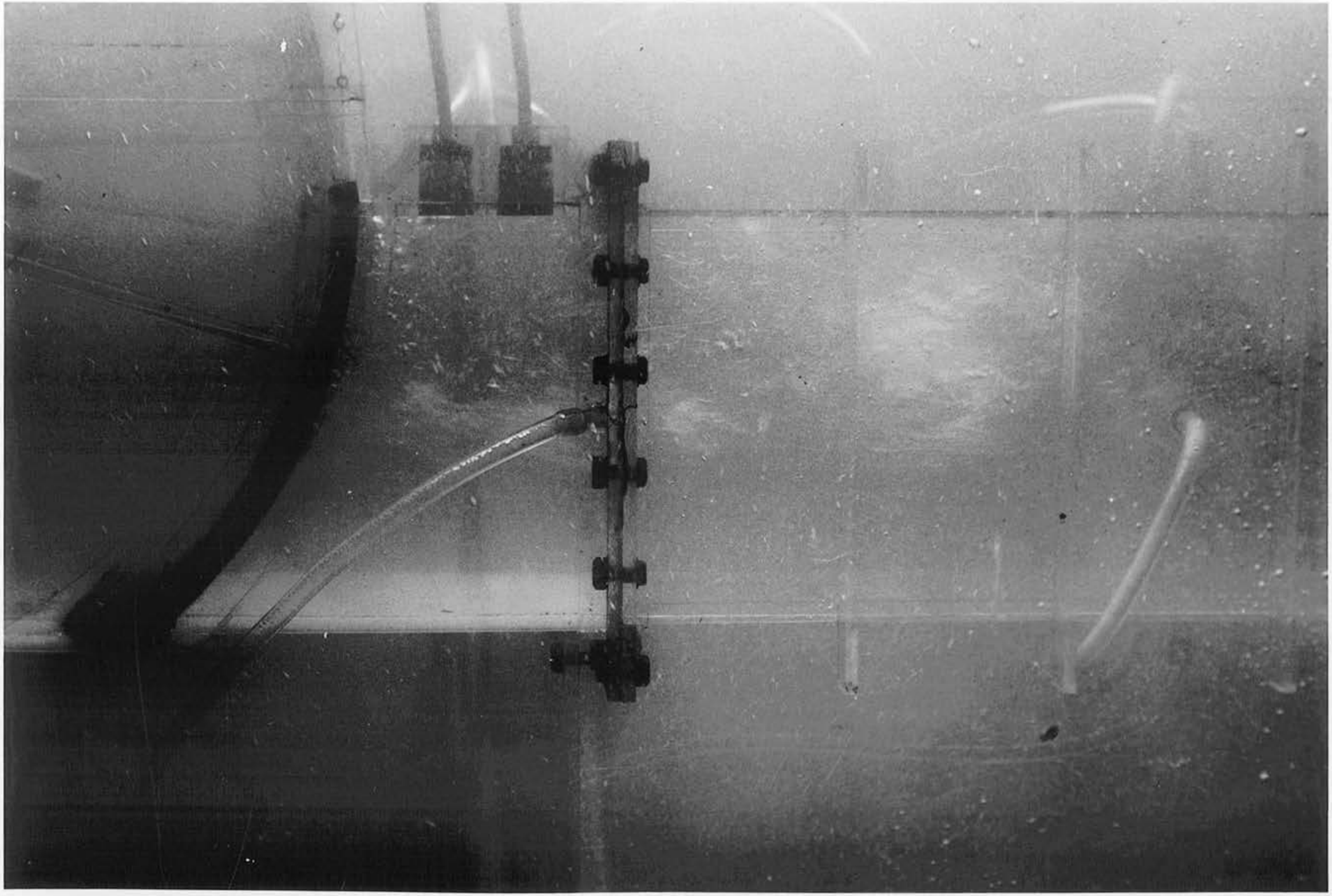
PHOTOGRAPH 1

PHOTOGRAPH 2

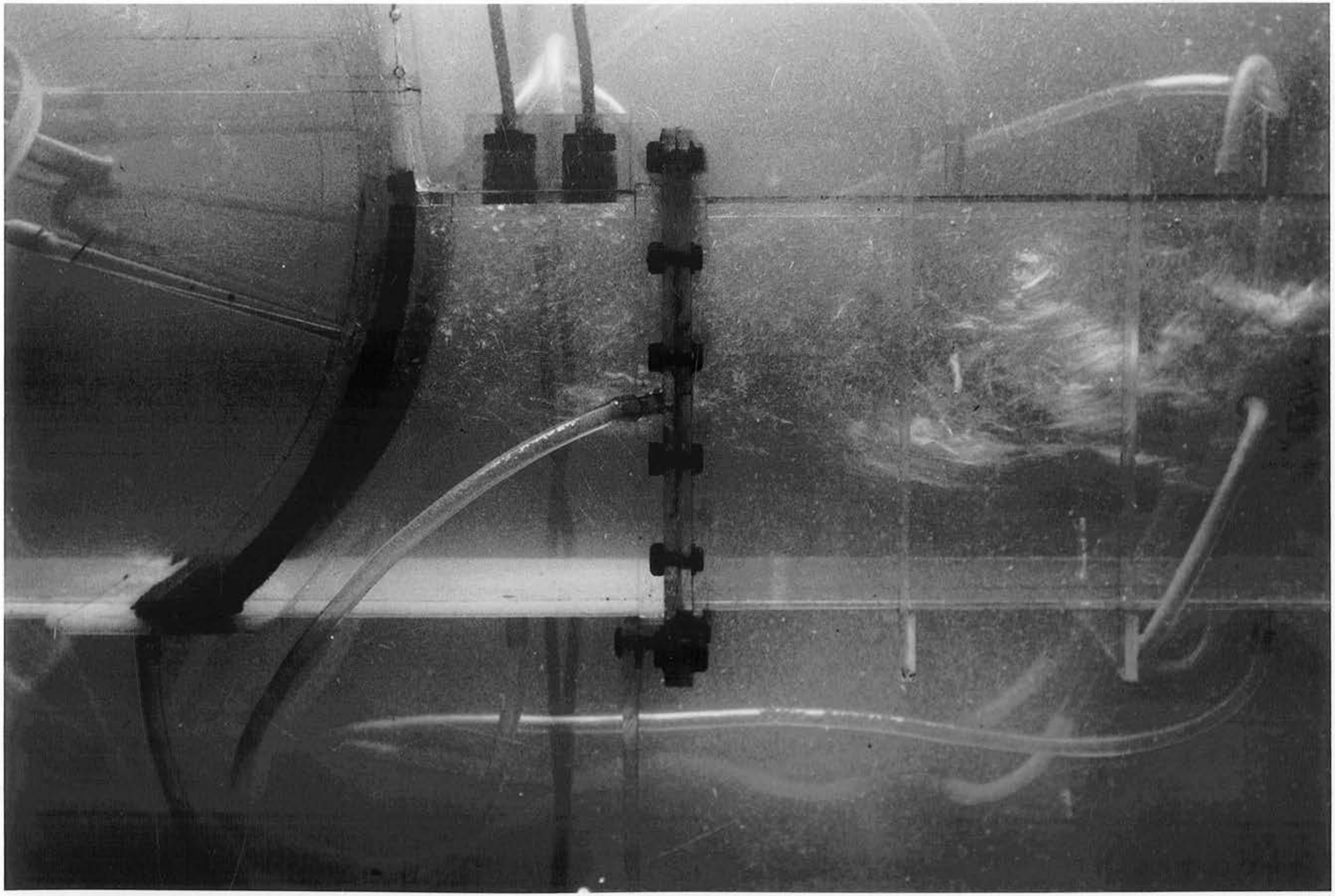


Culvert invert elev 223, tainter valve open 7 ft, discharge 4,780 cfs
Cavitation parameter at piezometer ring A = 6.28

PHOTOGRAPH 3

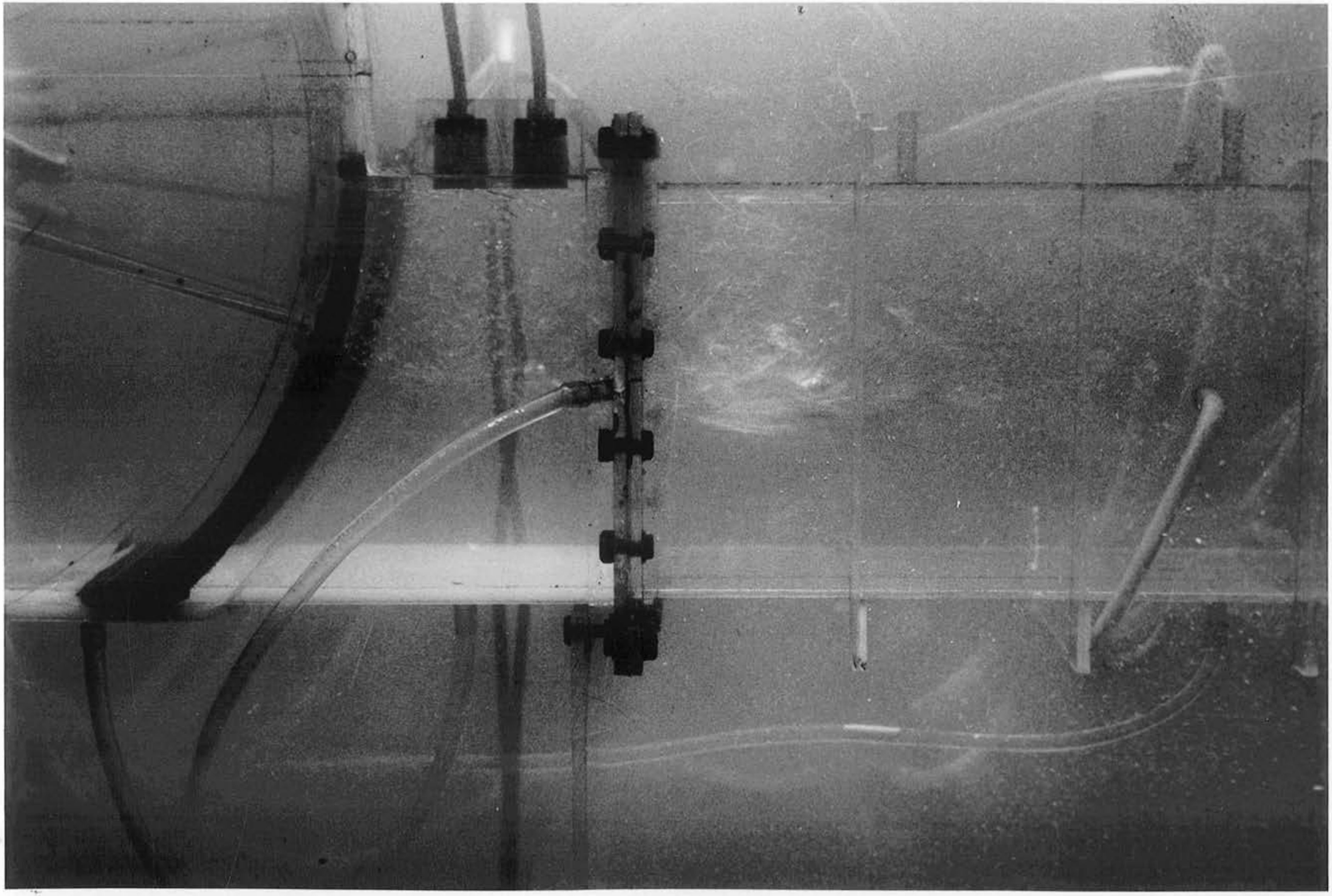


Culvert invert elev 218, tainter valve open 7 ft, discharge 4,780 cfs
Cavitation parameter at piezometer ring A = 6.53



Culvert invert elev 213, tainter valve open 7 ft, discharge 4,780 cfs
Cavitation parameter at piezometer ring A = 6.77

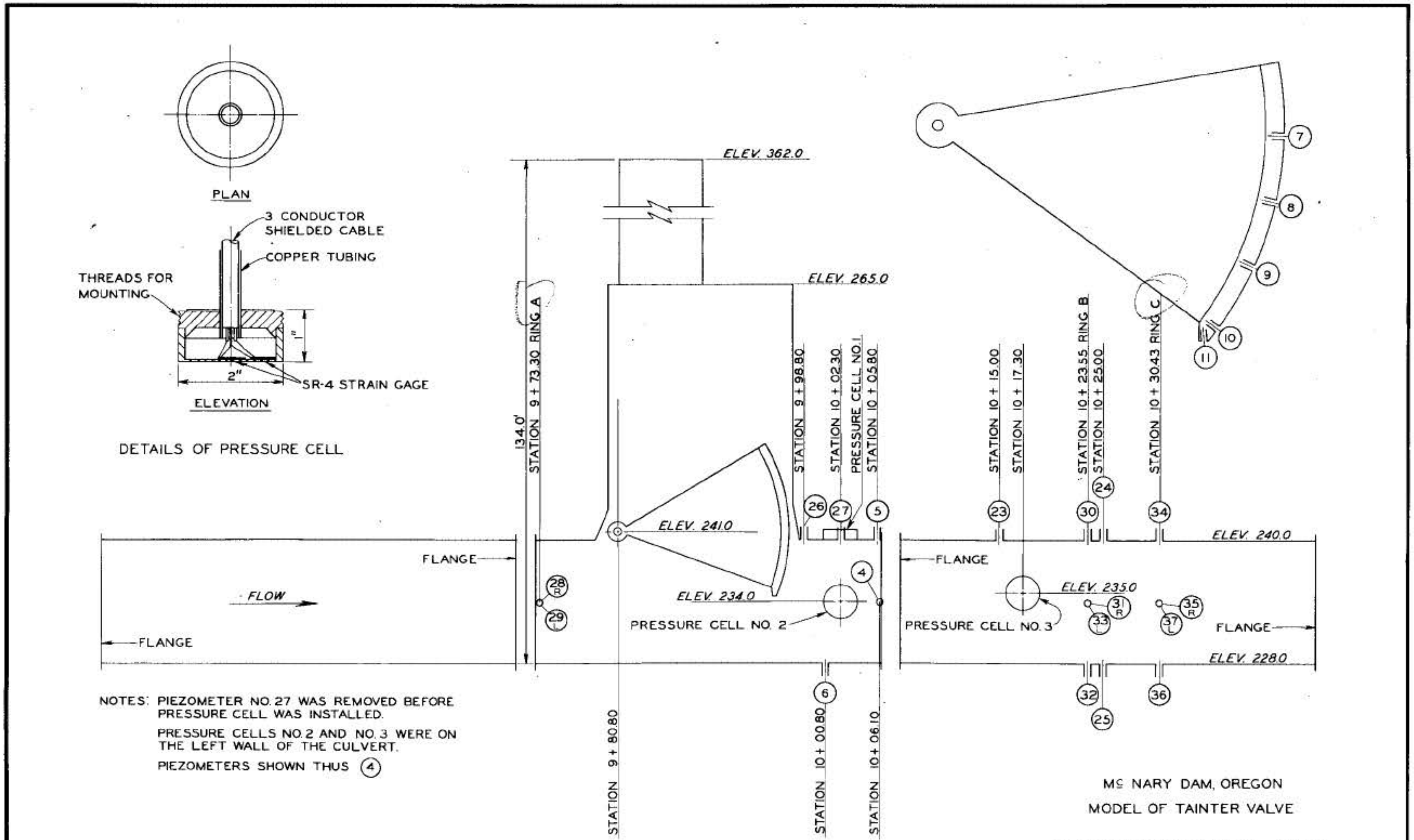
PHOTOGRAPH 5



Culvert invert elev 208, tainter valve open 7 ft, discharge 4,780 cfs
Cavitation parameter at piezometer ring A = 7.02

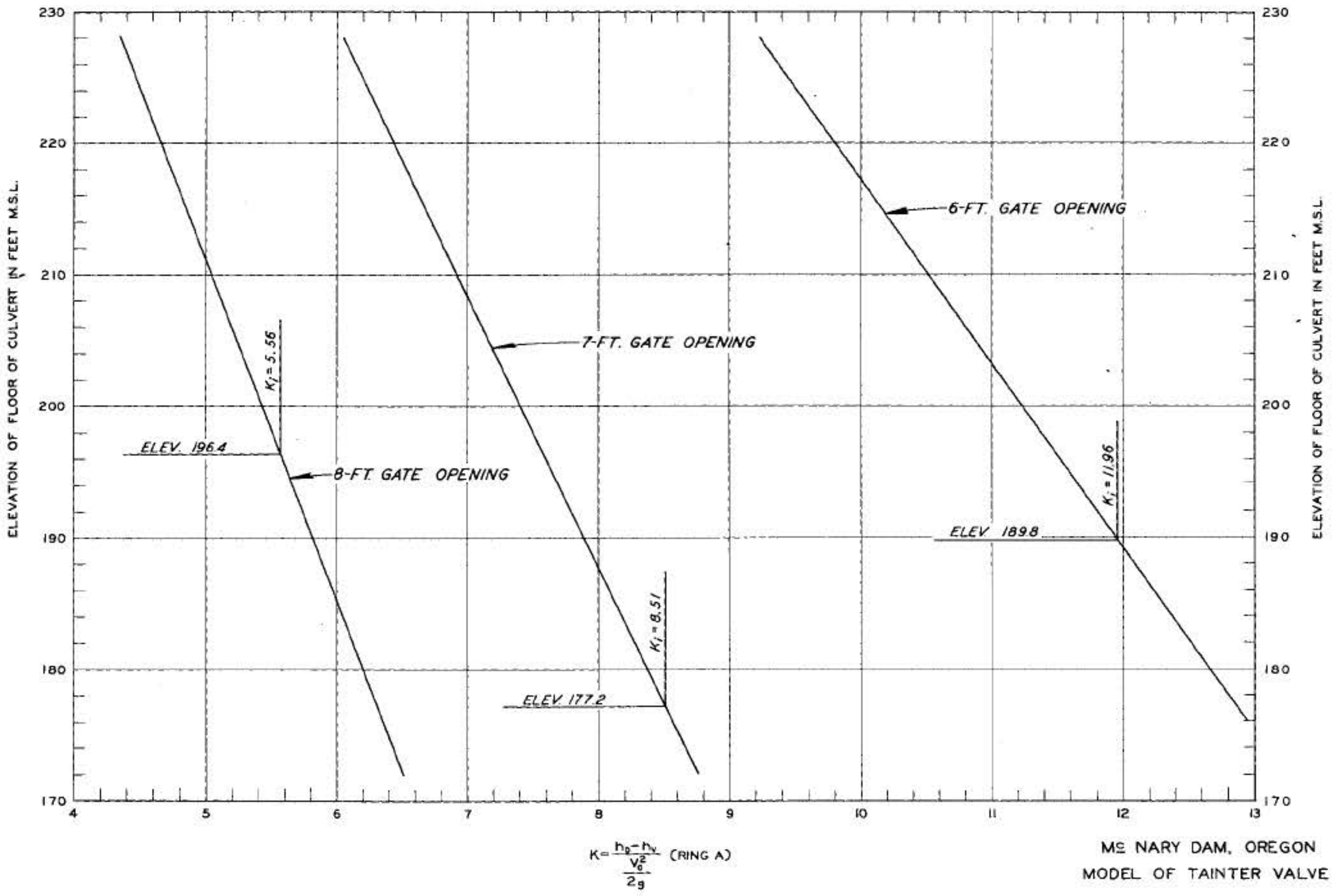
PHOTOGRAPH 6

Electric pressure cell



PRESSURE CELL AND PIEZOMETER LOCATIONS

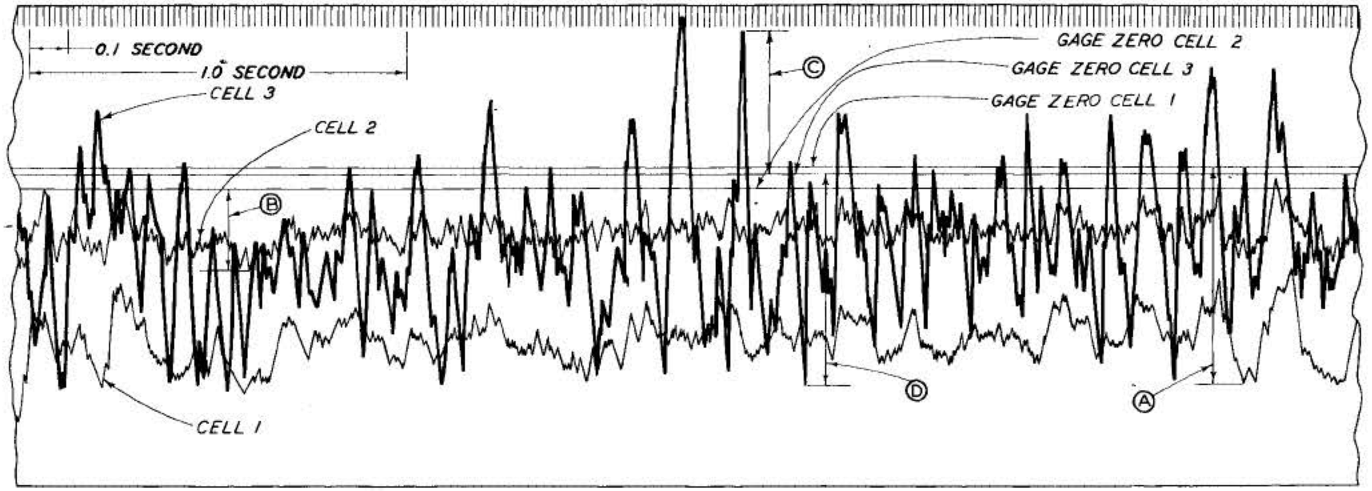
PLATE I



McNARY DAM, OREGON

MODEL OF TAINTER VALVE

CAVITATION PARAMETER VERSUS CULVERT INVERT ELEVATION

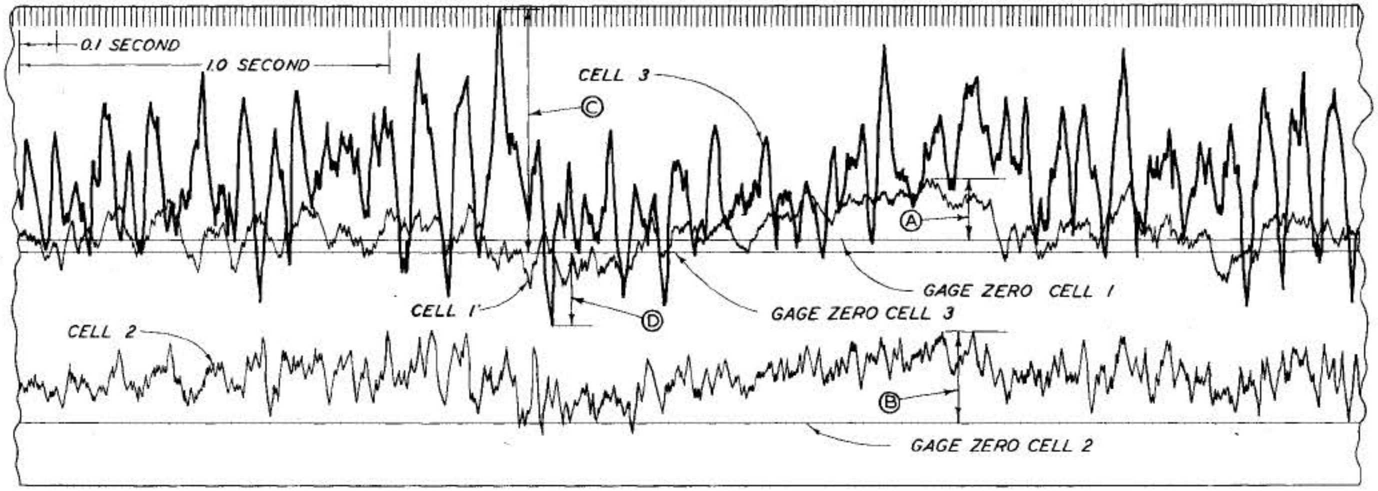


Ⓐ = −26.44 FEET OF WATER.
Ⓑ = −16.49 FEET OF WATER.
Ⓒ = 16.61 FEET OF WATER.
Ⓓ = −24.64 FEET OF WATER.

NOTE: VALVE OPEN 7.0 FEET.
DISCHARGE 4,780 C.F.S.
CAVITATION PARAMETER AT PIEZOMETER RING A = 6.04

MC NARY DAM, OREGON
MODEL OF TAINTER VALVE

TYPICAL OSCILLOGRAPH RECORD
CULVERT INVERT ELEVATION 228.0



Ⓐ = 10.34 FEET OF WATER.
Ⓑ = 19.10 FEET OF WATER.
Ⓒ = 37.36 FEET OF WATER.
Ⓓ = -13.19 FEET OF WATER.

NOTE: VALVE OPEN 7.0 FEET.
DISCHARGE 4,780 C.F.S.
CAVITATION PARAMETER AT PIEZOMETER RING A = 7.02

MC NARY DAM, OREGON
MODEL OF TAINTER VALVE

TYPICAL OSCILLOGRAPH RECORD
CULVERT INVERT ELEVATION 208.0